Opportunities for Detector Development In Synchrotron-Based Macromolecular Crystallography

1. INTRODUCTION:

There is no such thing as a perfect detector: each design has its virtues and problems.

Existing detectors for macromolecular crystallography are very good, but significantly better detectors can be made. Detector improvements will increase the productivity and value of existing and future synchrotron beamlines dedicated to macromolecular crystallography.

2. DIRECTIONS FOR DEVELOPMENT:

Current detector systems at beamlines dedicated to macromolecular crystallography are almost all of a single basic design. A phosphor screen converts incident X rays to visible light. This light image is reduced, by a coupling tapered fiberoptic light guide, onto a CCD (charge-coupled device) in which the light is converted to electric charge. The CCD is then read out electronically to form a digital, quantitative record of the image. Modules of these detector systems are clustered into arrays to cover larger areas. These systems are much better in many respects than previous detectors used in this scientific application, in terms of speed, efficiency, spatial resolution. They remain somewhat smaller than desired, their dynamic range is limited, and they are quite expensive. Also, it is desirable to have even faster, even more efficient detectors for this application. Finally, it would be desirable in many circumstances to have counting detection instead of analog detection.

3. EXISTING DETECTOR TECHNOLOGIES:

a. Multiwire Proportional Gas Chambers: are efficient at low count rates, are counting detectors, and are relatively inexpensive. Their efficiency plummets at count rates found on crystallographic synchrotron beamlines, they are inherently small, and their spatial resolution is modest.

b. Imaging Phosphor Plates: are big, exhibit reasonable spatial resolution, and are reasonably efficient. They are very slow.

c. CCD Systems: are more efficient than imaging phosphor plates, are faster than any other existing detection system in this field, and have better spatial resolution than imaging phosphor plates. They are small, so to cover large areas, detector designers must comb ine multiple systems in mosaic arrays. Dynamic range of CCD systems is limited, and they are very expensive. This is currently the “standard” detector technology in this field.

4. FUTURE TECHNOLOGIES:

a. Improved CCD array systems: can be made. They will remain expensive. The conventional detector system consists of a modular array of CCDs each with a tapered fiberoptic coupler that images an area of the phosphor film that converts incident X rays to light. Improvements include development of better phosphors, reduction of electronic noise, increased multiplexing of parallel readout (to increase speed), and increased numbers of modules (to increase size). Also, scientific grade CCDs continue to improve, so detectors featuring newer CCDs will get progressively better.

b. Amorphous silicon TFT arrays: are now being manufactured for medical imaging. Related to the electronic sysem in thin-panel computer monitor displays, these systems rely either on photoconversion by a scintillator deposited on the TFT array, or direct conversion to electric charge within a semiconducting photoconductor film coating the TFT array. Dynamic range of medical radiologic systems is currently about 12 bits, and thus must be increased if it is to be used for crystallography. Development of these systems for crystallographic applications requires research into electronic noise suppression and improved conversion thin films. This technology has substantial promise in this field, but requires engineering work. Large initial investments have been made in this technology by big companies (GE, Siemens, etc.), but they are not

interested in our very small market. To make this technology effective, it will probably be necessary to organize a large team and to enter into some kind of cooperative agreement with one of the large companies.

c. Silicon pixel array detectors: are under development for high energy physics applications. Two approaches for their use are possible: counting mode and analog mode. Counting mode detectors require dense, complex electronics on the readout chip, whereas analog mode readout is less complex but also less efficient. Pixel arrays are hybrids involving two chips: a sensor to directly convert X rays to charge; and a readout chip (CMOS) to process the charge into an electronic format. They are coupled by "bump bonds" of soft metal (indium, solder, etc.): one bond per pixel. A large investment has been made in this technology by the entire international high energy physics community, so many (but not all) engineering hurdles have been overcome. The complexity of this technology warrants formation of large development team(s) to apply it to synchrotron-based macromolecular crystallography.

d. Lens-coupled CCD systems: are under development for macromolecular crystallography. One prototype has been made by Bruker AXS Inc., and it is under active study. This approach continues to use CCD readout technology, but replaces the conventional fiberoptic taper coupling with lens coupling. Its virtues are very large size, improved spatial resolution over fiberoptic taper designs, and greatly reduced cost. Its problems are reduced sensitivity and reduced readout multiplexing (therefore reduced speed). Active development of this technology, to improve sensitivity and increase multiplexing number, is under way. It is likely this system will be available to the community within 2-3 years.

e. Porous dielectrics: are not under active development but hold promise. It is based on secondary electron emission from dielectrics in high electric fields. Large surfaces of porous dielectric can be made. X rays incident on them would generate electric charge that would be amplified in effect as an array of miniature photomultipliers. The readout uses any of a number of possible schemes. This technology was developed to a degree in Soviet Russia in the 1970's.

f. Avalanche photodiodes: are not under active development but hold promise. These devices are used in certain nuclear medicine applications, as point sensors. Arrays of APDs can be manufactured, but development of the technology for making these large-format systems is required.

g. Other technologies: There are others. This is merely a sampling of those that seem most likely to succeed over the next decade.